

## CONTENTS

CHAPTER	ITEM	PAGE
	<b>TITLE PAGE</b>	i
	<b>DECLARATION</b>	ii
	<b>DEDICATION</b>	iii
	<b>ACKNOWLEDGEMENT</b>	iv
	<b>ABSTRAK</b>	v
	<b>ABSTRACT</b>	vi
	<b>CONTENTS</b>	vii
	<b>LIST OF TABLES</b>	x
	<b>LIST OF FIGURES</b>	xiii
<b>I</b>	<b>INTRODUCTION</b>	
	1.0 Introduction	1
	1.1 Tunnel Segment Smart Tunnels	3
	1.2 Problem Statement	3
	1.3 Objectives	4
	1.4 Scope Of Study	4
	1.5 Research Methodology	5
<b>II</b>	<b>LITERATURE REVIEW</b>	
	2.0 Introduction	6
	2.1 Some Tunneling Problems	8

2.1.1	Geological Condition	8
2.1.2	Land Subsidence/Sinkholes	9
2.1.3	Gas Problems	10
2.1.4	Ground Stresses	11
2.2	Smart Tunnels Design Components	11
2.3	Effect Of Sumatran Earthquake Of 29 <sup>th</sup> March 2005 On Smart Tunnel	14
2.4	Seismic Hazards For Underground Structures	15
2.4.1	Earthquake Effect On Underground Structure	16
2.4.1.0	Ground Failure	16
2.4.1.1	Liquefaction	16
2.4.1.2	Fault Displacement	16
2.4.1.3	Slope Instability	17
2.4.2	Types of Deformation	17

### **III THEORETICAL BACKGROUND**

3.0	Introduction	19
3.1	Tunnel Analysis Procedure	20
3.2	Tunnel Assumption	20
3.3	Process Of Analysis	20
3.4	Non Linear Analysis	21
3.5	Basic Principles Of TBM And Definitions	22
3.6	Basic Principles And Construction	24
3.6.1	Open TBM.	24
3.6.2	TBM With Roof Shield	24

3.6.3	TBM With Roof Shield And Side Steering Shoes.	24
3.6.4	TBM With Cutter Head Shield.	25
3.6.5	Single Shield TBM.	25
3.6.6	Double Shield Or Telescopic Shield TBM.	26
3.6.7	Closed Systems.	27
3.7	Seismic Hazards	27
3.7.1	Ground Shaking	27
3.7.2	Liquefaction	28
3.7.3	Retaining Structure Failures	29
3.7.4	Lifeline Hazards	30
3.8	Practical Guide To Grouting Of Underground Structures	30
3.9	Grouting Method	32

## **IV                      RESULT AND DISCUSSION**

4.0	Introduction	34
4.1	Tunnel Structure	34
4.2	SAP 2000 Analysis Software	35
4.3	Tunnel Model	35
4.4	Two Dimensional Tunnel	37
4.5	Material Properties	38
4.6	Free Vibration Analysis	39
4.7	Time History Analysis (Model A)	40
4.8	Response Spectrum Analysis (Model A)	45
4.9	Time History Analysis (Model B)	48
4.10	Response Spectrum Analysis (Model B)	53
4.11	Time History Analysis (Model C)	56

4.12	Response Spectrum Analysis (Model C)	60
4.13	Design Capacity	63
4.14	Analysis Using Different Level Of Earthquake Intensities	64

**V****CONCLUSION AND RECOMMENDATION**

5.0	Introduction	68
5.1	Time History Analysis	68
5.2	Response Spectrum Analysis	70
5.3	Conclusion	71
5.4	Recommendation	72

**REFERENCES****APPENDIX A-G**

## LIST OF TABLES

TABLES	TITLE	PAGE
<b>Table 1.1</b>	Tunneling Activities From 1995 To 2005	2
<b>Table 4.1</b>	Coordinates Of SMART Tunnel Lining	36
<b>Table 4.2</b>	Material Properties For Soil Data	38
<b>Table 4.3</b>	Material Properties Tunnel Lining	38
<b>Table 4.4</b>	Period With Various Mode Shapes	40
<b>Table 4.5</b>	Maximum Lining Member Forces Value For Time History (Model A)	45
<b>Table 4.6</b>	Maximum Upper Deck Forces Value For Time History (Model A)	45
<b>Table 4.7</b>	Maximum Lower Deck Forces Value For Time History (Model A)	45
<b>Table 4.8</b>	Maximum Lining Member Forces Value For Response Spectrum (Model A)	48
<b>Table 4.9</b>	Maximum Upper Deck Forces Value For Response Spectrum (Model A)	48

<b>Table 4.10</b>	Maximum Lower Deck Forces Value For Response Spectrum (Model A)	48
<b>Table 4.11</b>	Maximum Lining Member Forces Value For Time History (Model B)	53
<b>Table 4.12</b>	Maximum Upper Deck Forces Value For Time History (Model B)	53
<b>Table 4.13</b>	Maximum Lower Deck Forces Value For Time History (Model B)	53
<b>Table 4.14</b>	Maximum Lining Member Forces Value For Response Spectrum (Model B)	55
<b>Table 4.15</b>	Maximum Upper Deck Forces Value For Response Spectrum (Model B)	55
<b>Table 4.16</b>	Maximum Lower Deck Forces Value For Response Spectrum (Model B)	56
<b>Table 4.17</b>	Maximum Lining Member Forces Value For Time History (Model C)	60
<b>Table 4.18</b>	Maximum Upper Deck Forces Value For Time History (Model C)	60
<b>Table 4.19</b>	Maximum Lower Deck Forces Value For Time History (Model C)	60
<b>Table 4.20</b>	Maximum Lining Member Forces Value For Response Spectrum (Model C)	62

<b>Table 4.21</b>	Maximum Upper Deck Forces Value For Response Spectrum (Model C)	62
<b>Table 4.22</b>	Maximum Lower Deck Forces Value For Response Spectrum (Model C)	63
<b>Table 4.23</b>	Design Capacity Of The SMART Tunnel Analysis (Lining)	63
<b>Table 4.24</b>	Design Capacity Of The SMART Tunnel Analysis (Deck)	63
<b>Table 4.25</b>	Lining Moment Capacity – 0.38g	66
<b>Table 4.26</b>	Deck Moment Capacity – 0.38g	66
<b>Table 4.27</b>	Lining Moment Capacity – 0.57g	66
<b>Table 4.28</b>	Deck Moment Capacity – 0.57g	66
<b>Table 4.29</b>	Lining Moment Capacity – 0.76g	67
<b>Table 4.30</b>	Deck Moment Capacity – 0.76g	67
<b>Table 5.1</b>	Summary Of Lining Member Forces For Time History Analysis	69
<b>Table 5.2</b>	Summary Of Upper Deck Member Forces For Time History Analysis	69
<b>Table 5.3</b>	Summary Of Lower Deck Lining Member Forces For Time History	69

<b>Table 5.4</b>	Summary Of Lining Member Forces For Response Spectrum Analysis	70
<b>Table 5.5</b>	Summary Of Upper Deck Member Forces For Response Spectrum Analysis	70
<b>Table 5.6</b>	Summary Of Lower Deck Lining Member Forces For Response Spectrum	70



## LIST OF FIGURES

<b>FIGURES</b>	<b>TITLE</b>	<b>PAGE</b>
<b>Figure 1.6.1</b>	Process Of The Research	5
<b>Figure 2.1.1.1 &amp; 2.1.1.2</b>	Heavy Steel Sets In Highly Sheared Granite, Sg. Selangor Dam Diversion Tunnel.	8
<b>Figure 2.1.2.1</b>	Schematic Section of Kuala Lumpur Limestone Formation	9
<b>Figure 2.1.2.2</b>	Karstic Limestone Bedrock Pinnacles Exposed During Mining, Sungai Way (Now Bandar Sunway In Petaling Jaya), A Former Suburb Kuala Lumpur.	10
<b>Figure 2.2.1</b>	SMART Tunnel Component.	12
<b>Figure 2.2.2</b>	Motorway Tunnel Cross Section	12
<b>Figure 2.2.3</b>	Three Mode Operation	13
<b>Figure 2.3.1</b>	Map Of Earthquake Zone	15
<b>Figure 2.4.1</b>	Deformation Modes Of Tunnels Due To Seismic Waves (After Owen And Scholl, 1981)	18

<b>Figure 3.4.1</b>	Concrete Stress-Strain Curve	21
<b>Figure 4.4.1</b>	Model A	37
<b>Figure 4.4.2</b>	Model B	37
<b>Figure 4.4.3</b>	Model C	37
<b>Figure 4.4.4</b>	Legend	37
<b>Figure 4.6.1</b>	Mode Shapes On Model A	39
<b>Figure 4.7.1</b>	Ground Acceleration Of Rapid KL	40
<b>Figure 4.7.2</b>	The Maximum Axial Force Of The Deck And Lining ( <i>Model A</i> )	41
<b>Figure 4.7.3</b>	Axial Force Of The Tunnel (By Time Period Of The Earthquake) At Frame 19,26 ( <i>Model A</i> )	41
<b>Figure 4.7.4</b>	Axial Force Of The Tunnel (By Time Period Of The Earthquake) At Frame 52 ( <i>Model A</i> )	42
<b>Figure 4.7.5</b>	Axial Force Of The Tunnel (By Time Period Of The Earthquake) At Frame 53 ( <i>Model A</i> )	42
<b>Figure 4.7.6</b>	The Maximum Shear Force Of The Deck And Lining ( <i>Model A</i> )	43
<b>Figure 4.7.7</b>	Shear Force Of The Tunnel (By Time Period Of The Earthquake) At Frame 16,30 ( <i>Model A</i> )	43

<b>Figure 4.7.8</b>	The Maximum Moment Of The Deck And Lining ( <i>Model A</i> )	44
<b>Figure 4.8.1</b>	Response Spectrum Of Rapid KL	46
<b>Figure 4.8.2</b>	The Maximum Axial Force Of The Deck And Lining ( <i>Model A</i> )	46
<b>Figure 4.8.3</b>	The Maximum Shear Force Of The Deck And Lining ( <i>Model A</i> )	47
<b>Figure 4.8.4</b>	The Maximum Moment Of The Deck And Lining ( <i>Model A</i> )	47
<b>Figure 4.9.1</b>	The Maximum Axial Force Of The Deck And Lining ( <i>Model B</i> )	49
<b>Figure 4.9.2</b>	Axial Force Of The Tunnel (By Time Period Of The Earthquake) At Frame 7,14 ( <i>Model B</i> )	49
<b>Figure 4.9.3</b>	Axial Force Of The Tunnel (By Time Period Of The Earthquake) At Frame 52 ( <i>Model B</i> )	50
<b>Figure 4.9.4</b>	Axial Force Of The Tunnel (By Time Period Of The Earthquake) At Frame 53 ( <i>Model B</i> )	50
<b>Figure 4.9.5</b>	The Maximum Shear Force Of The Deck And Lining ( <i>Model B</i> )	51
<b>Figure 4.9.6</b>	Shear Force Of The Tunnel (By Time Period Of The Earthquake) At Frame 16,30 ( <i>Model B</i> )	51

<b>Figure 4.9.7</b>	The Maximum Moment Of The Deck And Lining ( <i>Model B</i> )	52
<b>Figure 4.10.1</b>	The Maximum Axial Force Of The Deck And Lining ( <i>Model B</i> )	54
<b>Figure 4.10.2</b>	The Maximum Shear Force Of The Deck And Lining ( <i>Model B</i> )	54
<b>Figure 4.10.3</b>	The Maximum Moment Of The Deck And Lining ( <i>Model B</i> )	55
<b>Figure 4.11.1</b>	The Maximum Axial Force Of The Deck And Lining ( <i>Model C</i> )	56
<b>Figure 4.11.2</b>	Axial Force Of The Tunnel (By Time Period Of The Earthquake) At Frame 19,26 ( <i>Model C</i> )	57
<b>Figure 4.11.3</b>	Axial Force Of The Tunnel (By Time Period Of The Earthquake) At Frame 52 ( <i>Model C</i> )	57
<b>Figure 4.11.4</b>	Axial Force Of The Tunnel (By Time Period Of The Earthquake) At Frame 53 ( <i>Model C</i> )	57
<b>Figure 4.11.5</b>	The Maximum Shear Force Of The Deck And Lining ( <i>Model C</i> )	58
<b>Figure 4.11.6</b>	Shear Force Of The Tunnel (By Time Period Of The Earthquake) At Frame 16,30 ( <i>Model C</i> )	58
<b>Figure 4.11.7</b>	The Maximum Moment Of The Deck And Lining ( <i>Model C</i> )	59

<b>Figure 4.12.1</b>	The Maximum Axial Force Of The Deck And Lining ( <i>Model C</i> )	61
<b>Figure 4.12.2</b>	The Maximum Shear Force Of The Deck And Lining ( <i>Model C</i> )	61
<b>Figure 4.12.3</b>	The Maximum Moment Of The Deck And Lining ( <i>Model C</i> )	62
<b>Figure 4.14.1</b>	0.38g Simulated Of Rapid KL Time History	64
<b>Figure 4.14.2</b>	0.57g Simulated Of Rapid KL Time History	65
<b>Figure 4.14.3</b>	0.76g Simulated Of Rapid KL Time History	65